# Development and Operation of Acoustic Fish Deterrent Systems at Estuarine Power Stations

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# Acoustic Guidance: the Bigger Picture

- Not now considered an experimental technology: some 60 systems installed in Europe
- Systems suitable for lakes & rivers as well as estuaries & sea
- High efficiencies achievable
- Can also be used for interim or adjunct fish protection measure

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# Overview

- The fish impingement issue
- Principles of acoustic guidance
- Implementation of acoustic barriers
- Power plant trials
- Required sound levels
- Conclusions

# Fish Impingement: Issues

**Key Drivers**

- **Conservation Laws**
- **'Green' Image**
- **Plant Operation Issues**

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# Fish Impingement: Composition

*-Mainly pelagics (herrings, smelts)*

# Principles of Acoustic Guidance

- Many fish species react to underwater sound (e.g. from trawlers, seismic surveys)
- Peak sensitivity mainly from a few Hz to 3kHz
- Repellent sounds can be produced using electrical or pneumatic transducers

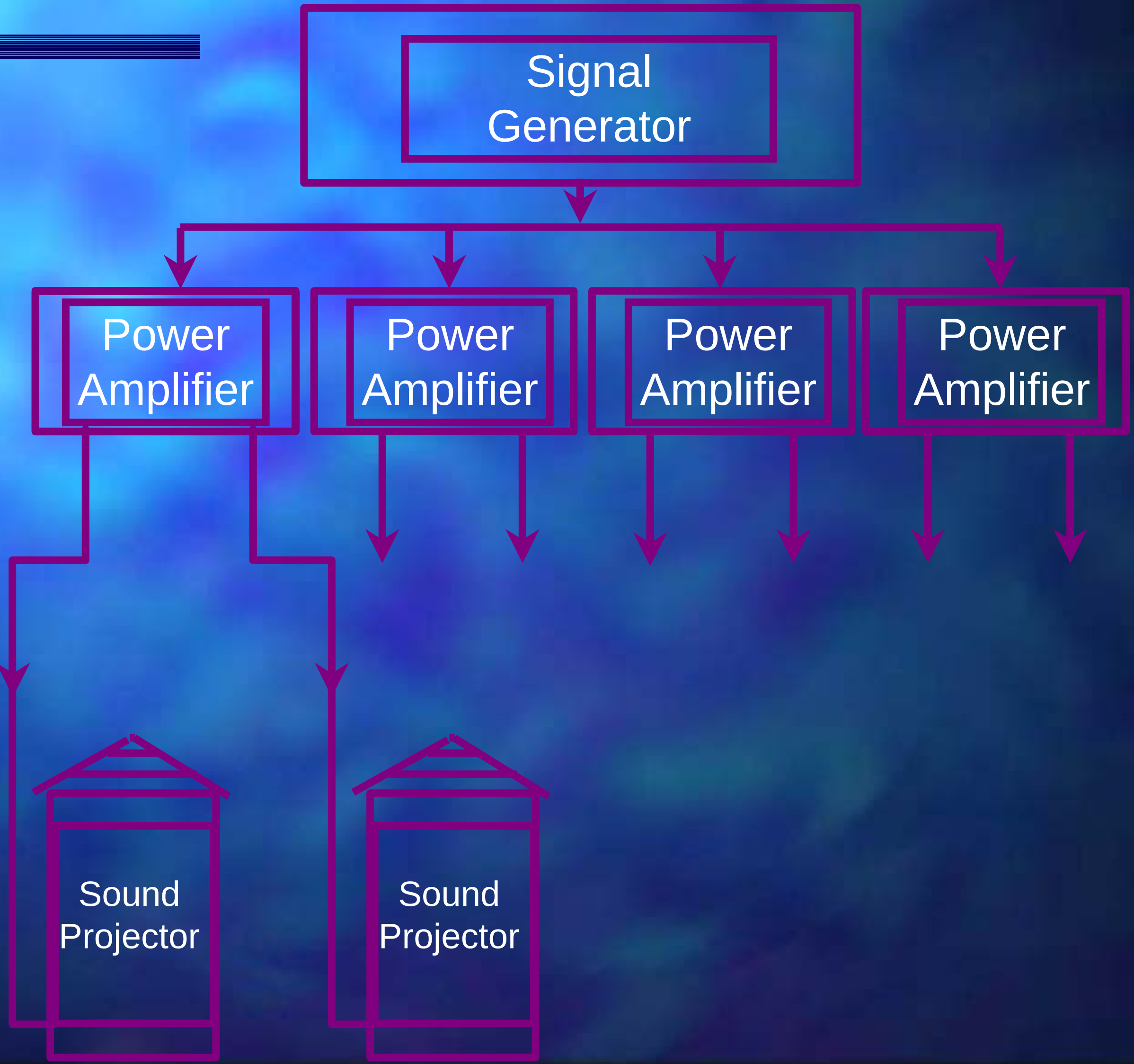
# Requirements for Acoustic Guidance

- Signal must be in suitable frequency range
- It must be in a form & at a level above background sufficient to cause repulsion
- Hydraulic conditions must be suitable for fish escape (e.g. approach velocity)

# Sensitivity to Sound Pressure

- Presence/absence of swimbladder (e.g. poor in flatfish & other benthic spp.)
- Auditory specialisations (e.g. couplings from swimbladder to inner ear in clupeids, cyprinids, etc.)
- Hence reactions to sound expected to vary among spp.
- Clupeids & salmonids have been most common target spp.

# Schematic of a SPA Acoustic Barrier



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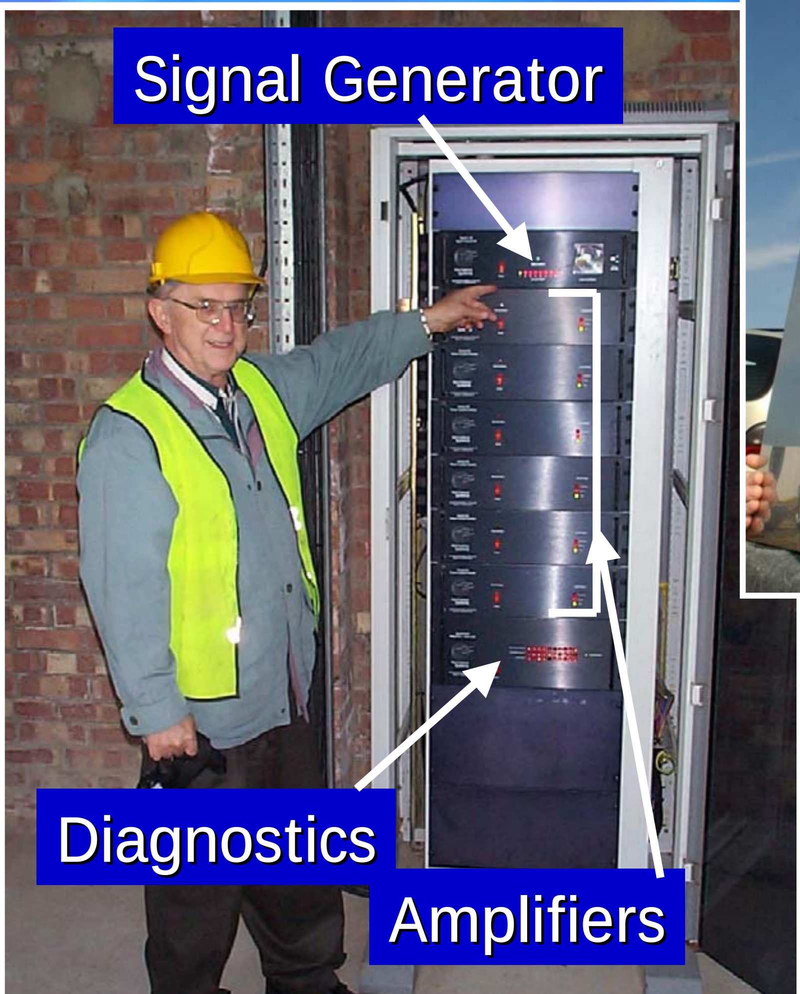
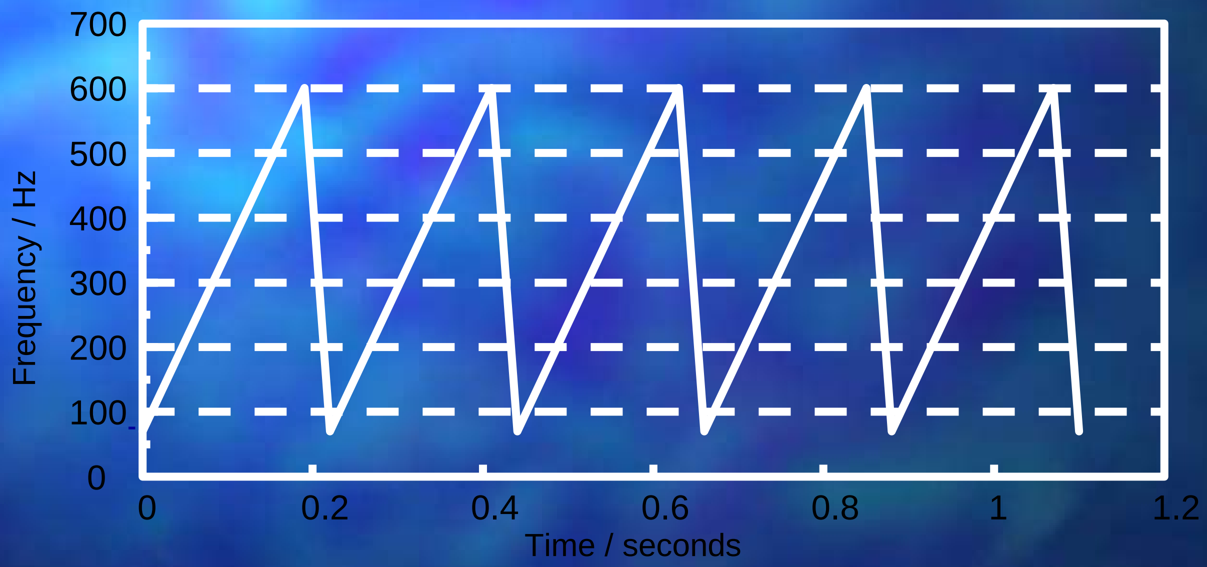
# SPA Components




Sound Projectors

# Typical Deterrent Sound Signal

A variety of sound signals is used. These are typically in the frequency range <3 kHz and are continuously changing, e.g.:



# Power Plant Trials

## Hartlepool, UK

- Estuary: R. Tees
- CW flow: 34 $m^3s^{-1}$
- Intake location: shoreline
- Catch rates: 85-15,427$d^{-1}$
- Main spp(>90%): *Sprattus sprattus, Clupea harengus, Merlangius merlangus*

## Doel 3/4, Belgium

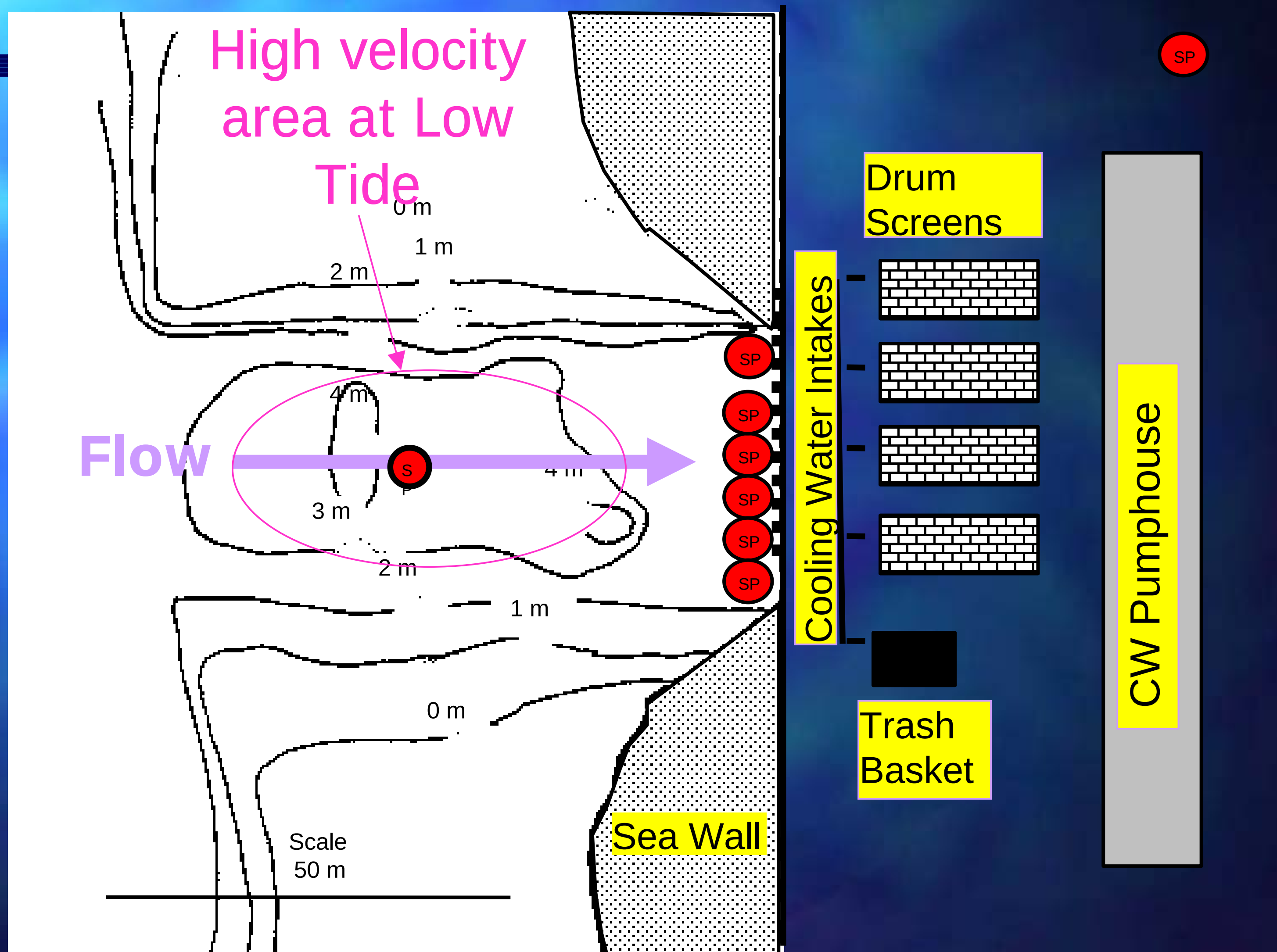
- Estuary: Zeeschelde
- CW flow: 25.1 $m^3s^{-1}$
- Intake location: offshore
- Catch rates($x10^3$): 1,265-77,000$d^{-1}$
- Main spp(>90%): *Sprattus sprattus, Clupea harengus, Stizostedion lucioperca*

# Test Programme

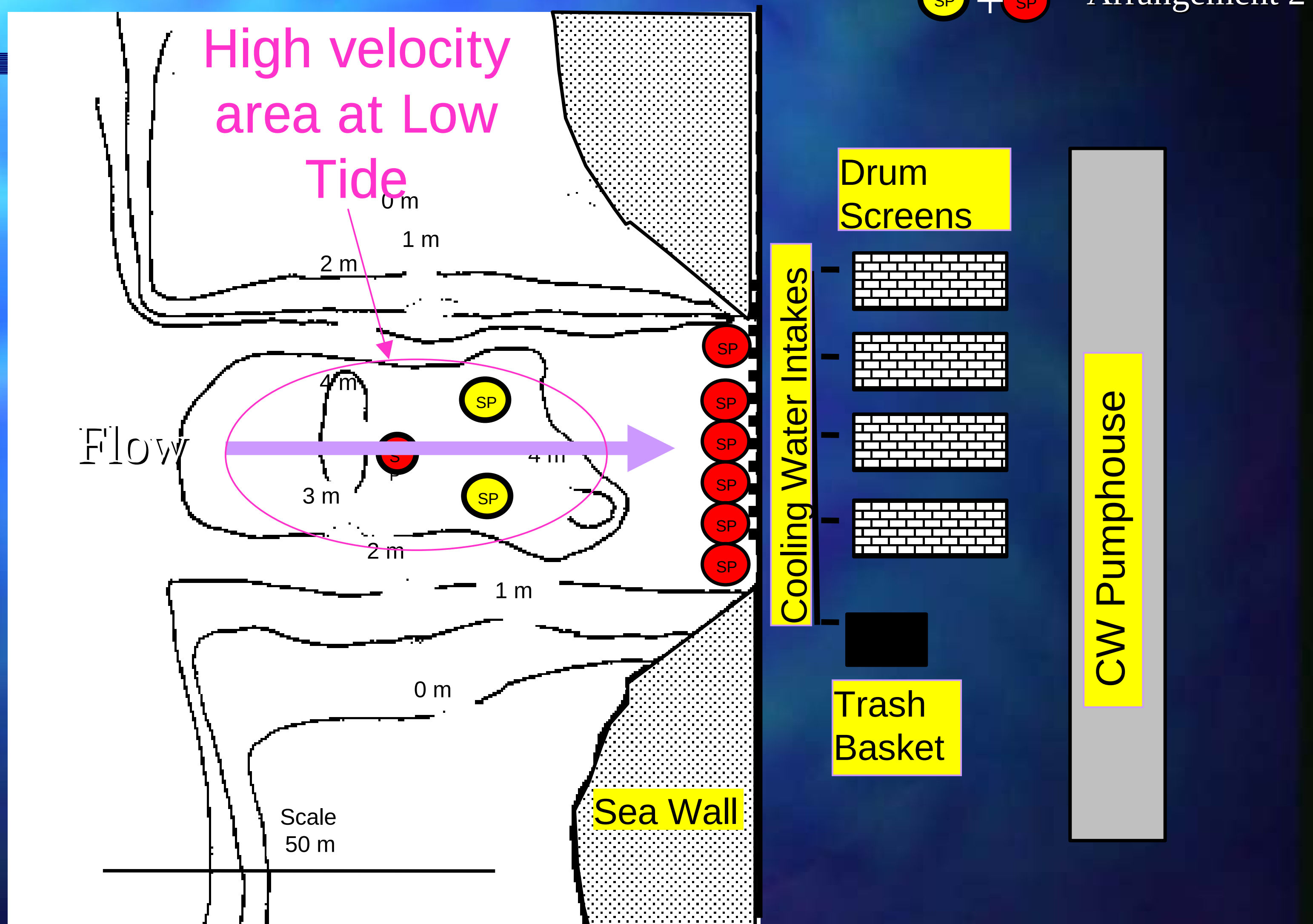
- Fish catch on screens compared for 24h sound ‘on’ vs. ‘off’
- Comparisons repeated for  at least 44 test-days (Hartlepool within 1 spring season; Doel, spread over 4 years
- Transit time from intake checked with live fish: 60-80% <1 h

# Hartlepool

# Hartlepool Layout – Plan View *(Arrangement 1)*



# Hartlepool Layout –Plan View *(Arrangement 2)*



# Hartlepool

## Changes in Daily PG-Mean Catch with Sound 'On' (Student's t-test)

| Species | Arrangement 1 | |
|---|---|---|
| All spp. | -2.1% (ns) | |
| Sprat | +33.1% (ns) | |
| Herring | -38.5% (P<0.05) | |
| Whiting | +19.8% (ns) | |
| Non-swim-bladder spp | +25.9% (ns) | |

# Hartlepool

## Changes in Daily PG-Mean Catch with Sound 'On' (Student's t-test)

| Species | Arrangement 1 | Arrangement 2 |
|---|---|---|
| All spp. | -2.1% (ns) | -55.9% ($P<0.05$) |
| Sprat | +33.1% (ns) | -60.1% ($P<0.05$) |
| Herring | -38.5% ($P<0.05$) | -79.6% ($P<0.05$) |
| Whiting | +19.8% (ns) | -53.5% ($P<0.05$) |
| Non-swim-bladder spp | +25.9% (ns) | -15.6% (ns) |

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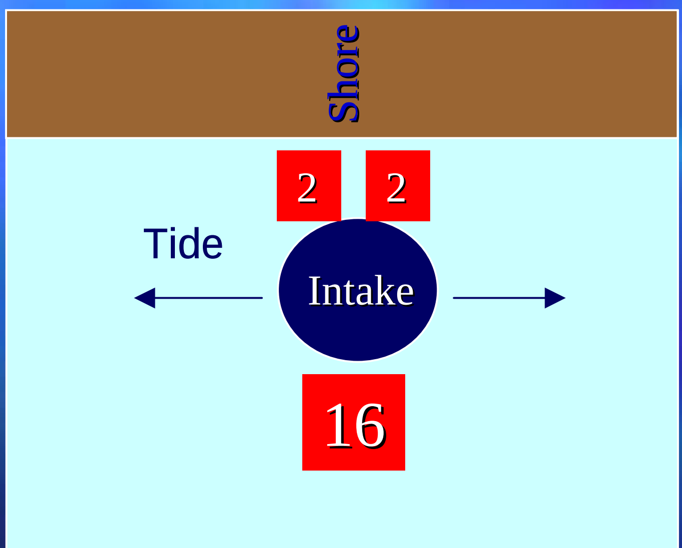
# Hartlepool Summary

- Significant reductions in impingement achieved using sound
- Response varied among different groups: Pelagic>Demersal>Benthic

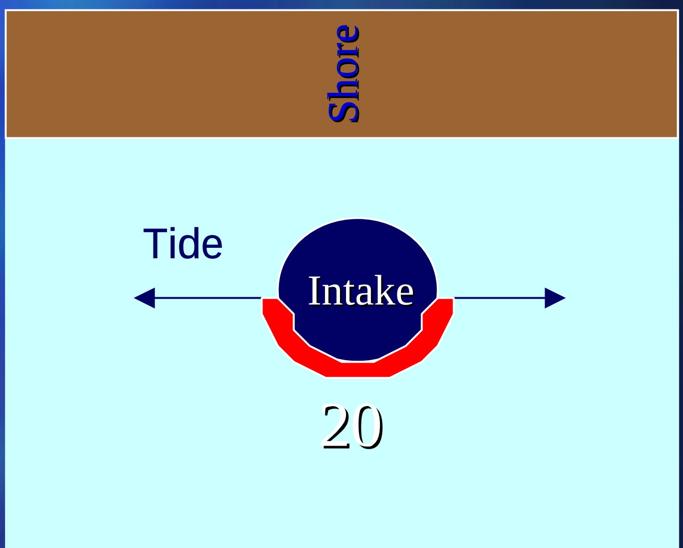
# Doel Nuclear Plant, Belgium

# Doel Units 3 /4 Trials

Two sound projector arrangements used (20 amplifiers, 20 sound projectors):

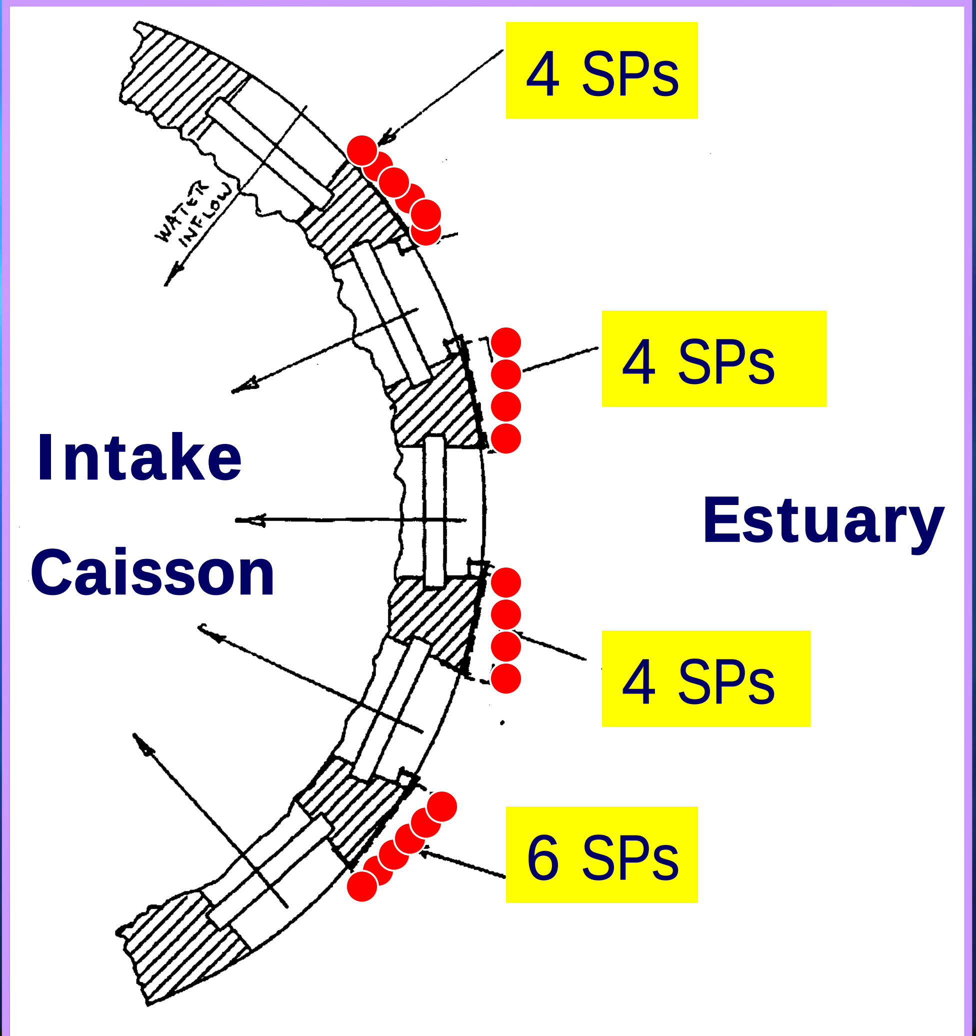



Arrangement 1
June '97-Feb'98

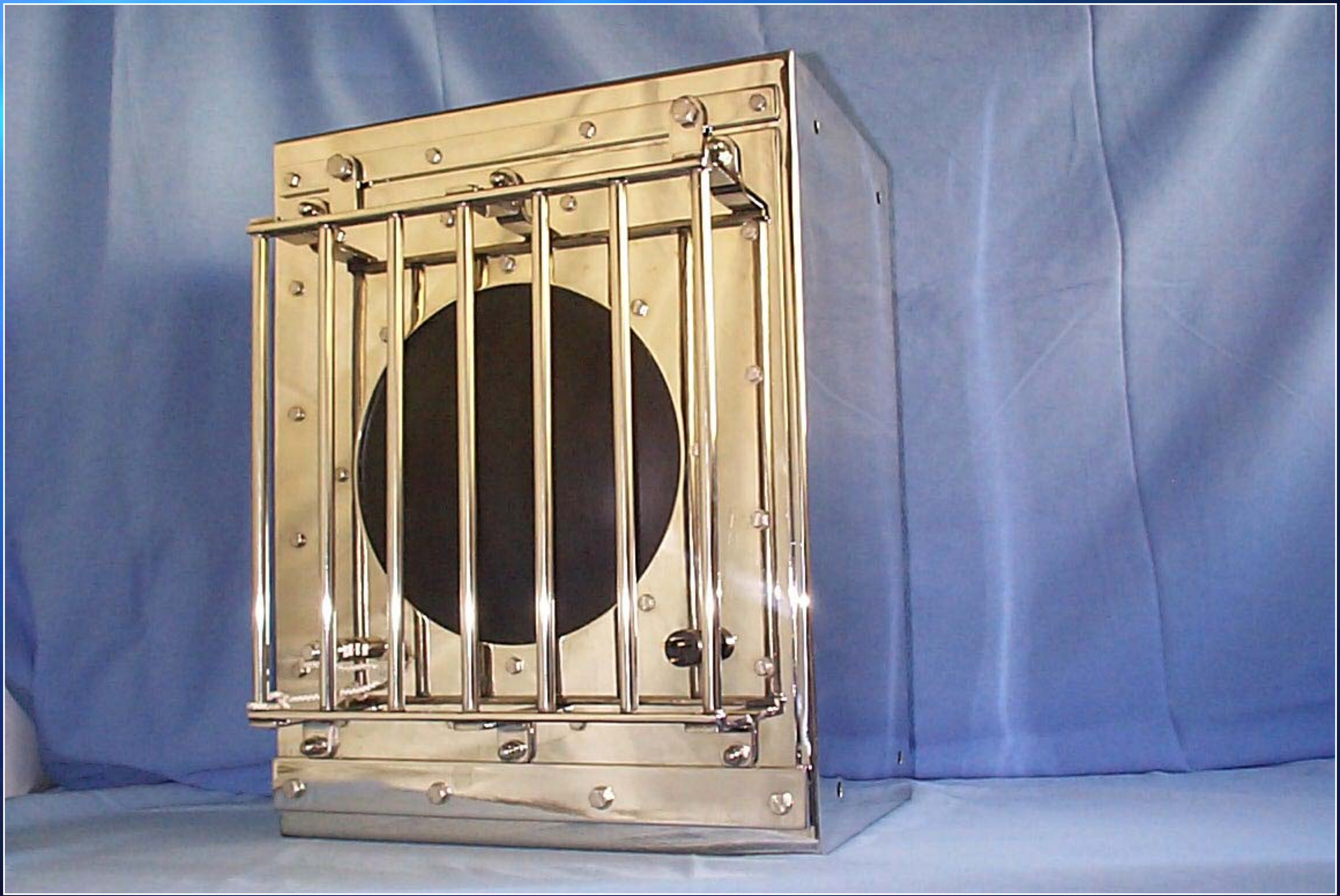



Arrangement 2
Oct '98 ==>

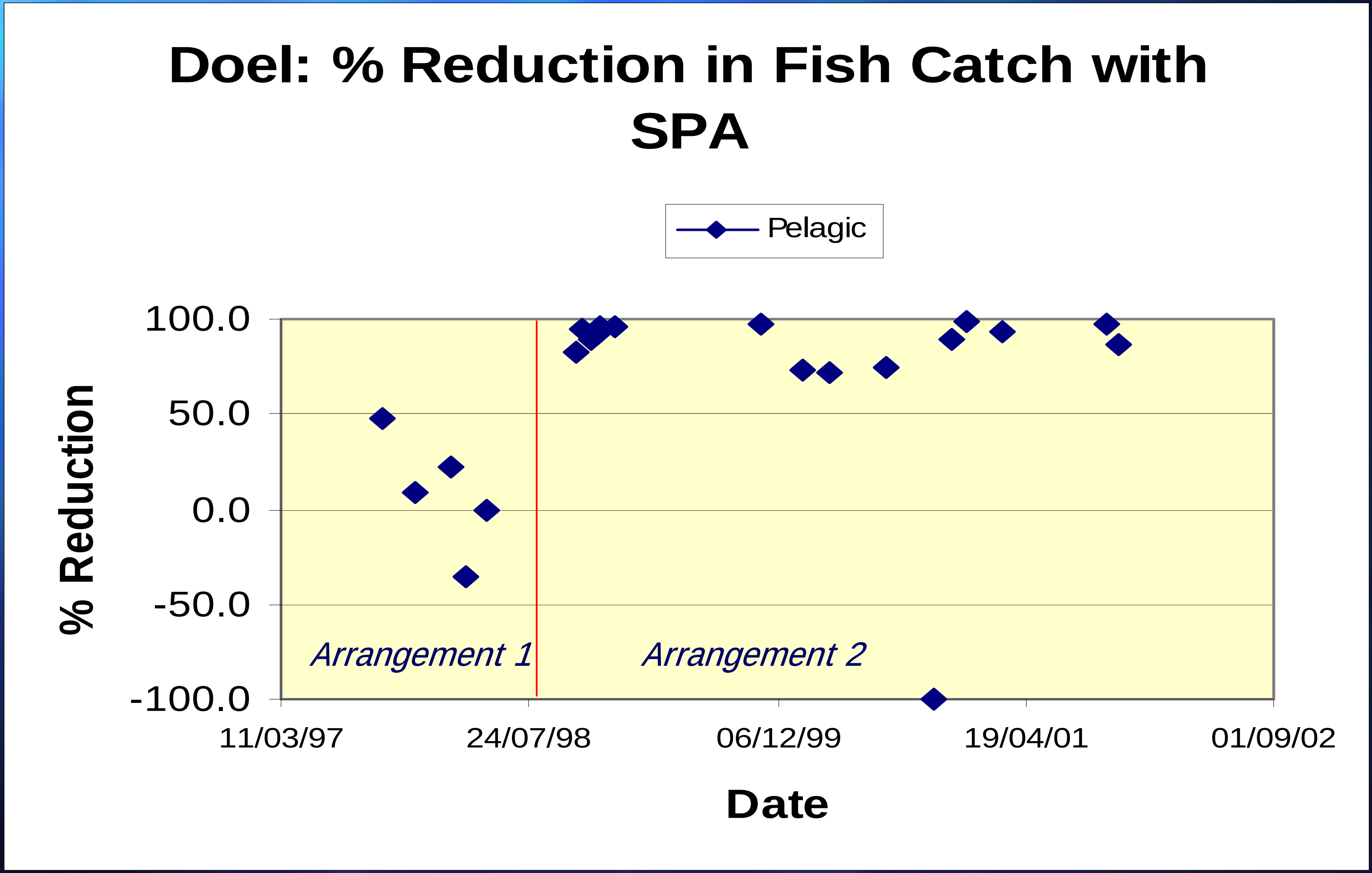
# Doel Sound Projector Layout- *Arrangement 2*



# FGS 30-600 Mk 2 Sound Projectors used at Doel

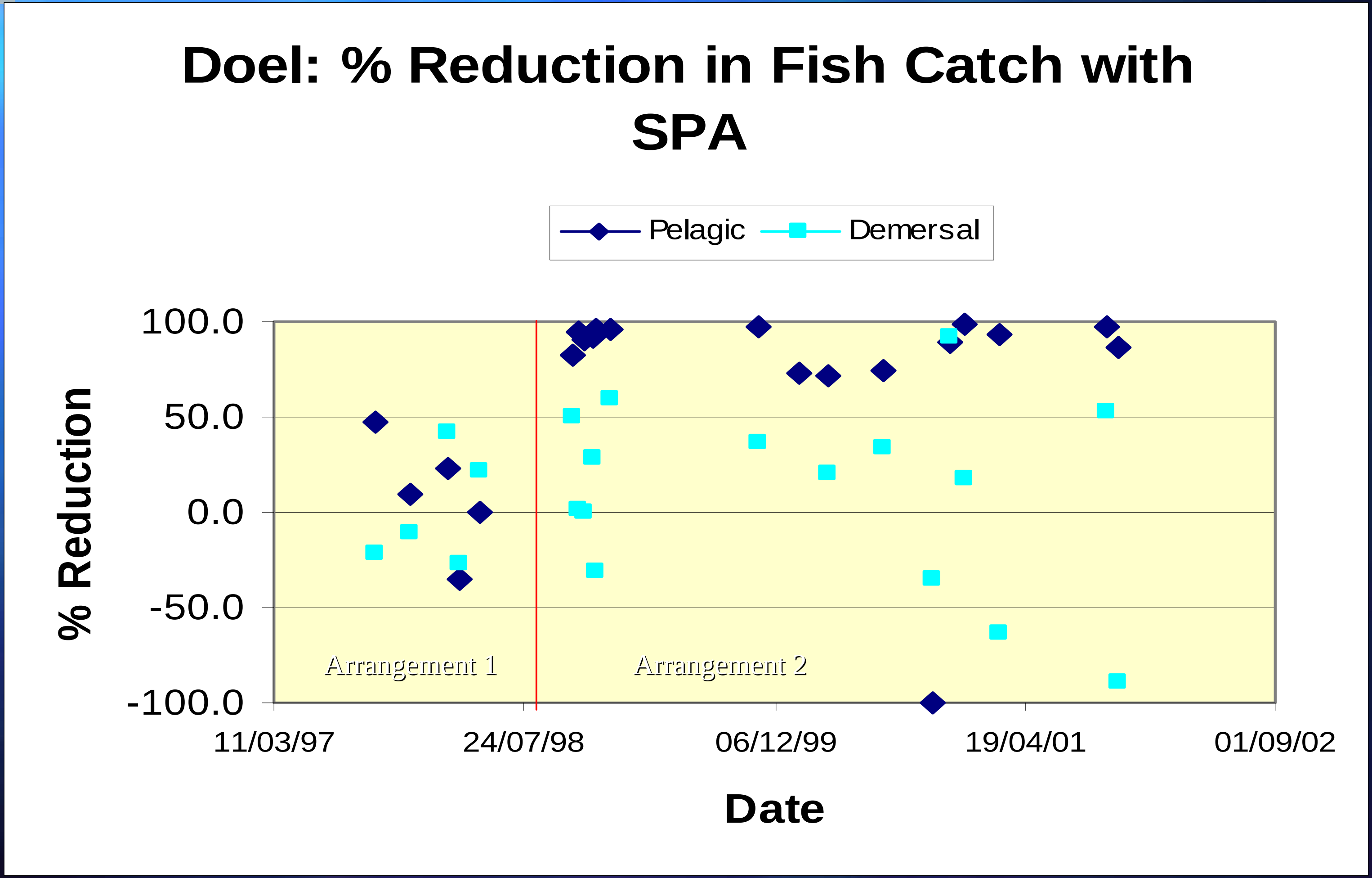


# Doel Results
# *Pelagic spp.*

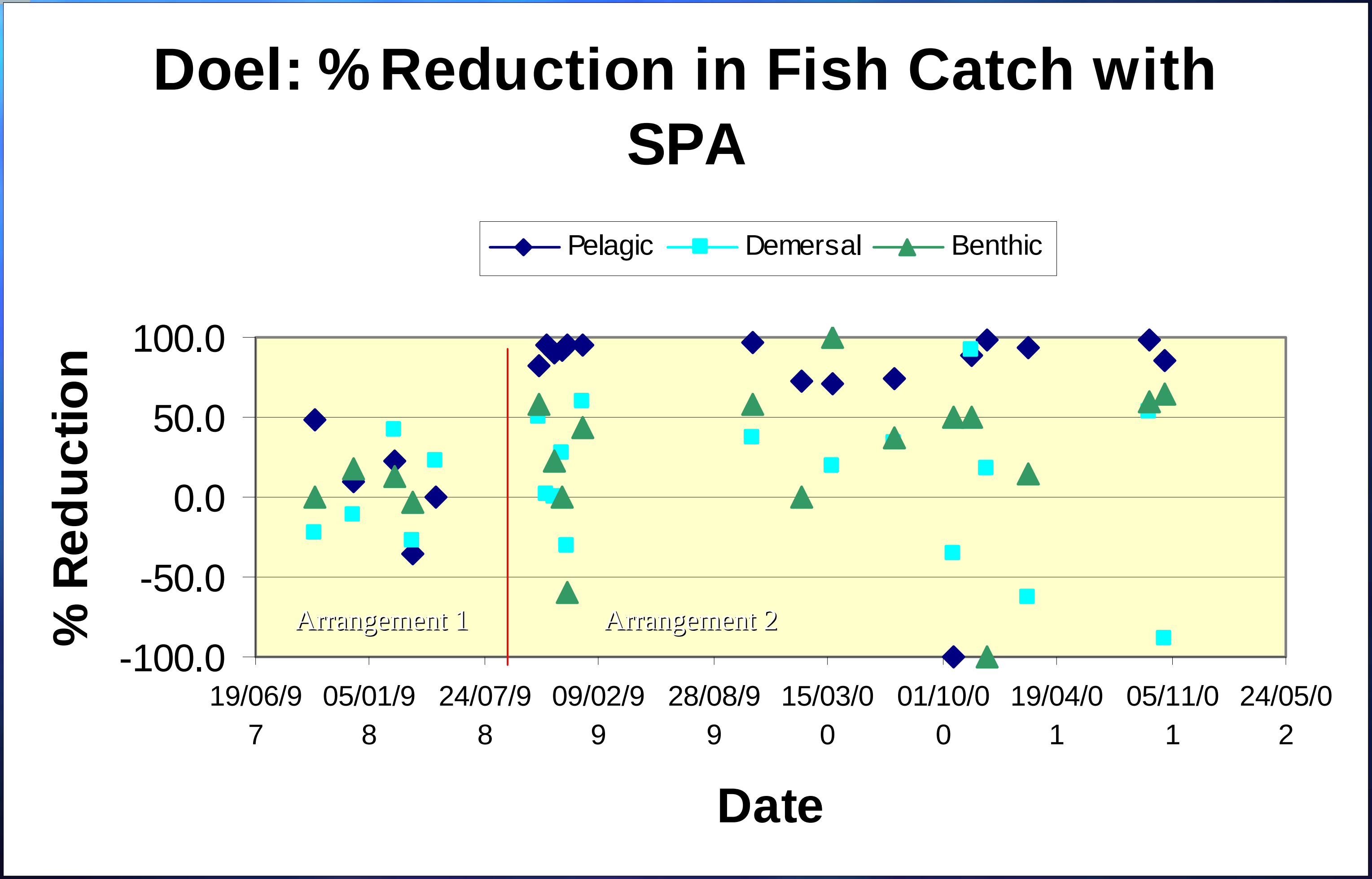


# Doel Results

# *Pelagic & Demersal spp.*



# Doel Results
# *All spp.*

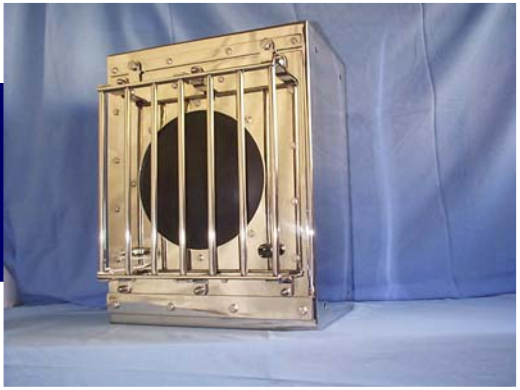


# Conclusions (1)

- **SPA Acoustic deterrent systems using suitable low-frequency sound signals are effective in reducing fish impingement**
- **Effectiveness depends on sensitivity to sound pressure (swimbladder)**
- **Position of sound projectors is critical (interference, background noise)**

# Conclusions (2)

## *BAT* for Estuarine Plant? SPA +Fish Return System



**FGS SPA Systems have been fitted/tested at the following European estuarine power plants:**

- Hartlepool (UK)
- Great Yarmouth (UK)
- Shoreham (UK)
- Doel (Belgium)

As well as at >30 freshwater sites.

# Interpretation of Recent Measurements of the Efficiency of an Acoustic Fish Deterrent System

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# Doel: Summary

- Moving SPA in close to intake improved effectiveness
- SPA system highly effective for clupeids (main target species)
- Latest results show consistently >90% for clupeids
- SPA, with fish return option, proved best solution for Doel.

*Fish Return System*

# Doel: Percentage Change in Fish Catch with SPA (*Arr. 1 & 2)*

| Fish Habit | Arrangement 1 | Arrangement 2 |
|---|---|---|
| Pelagic | -29.2 (ns) | -80.3 (P<0.01) |
| Demersal | -10.3 (ns) | -21.7 (P<0.02) |
| Benthic | 47.8 (ns) | -24.1 (ns) |

# Engineering AFD systems

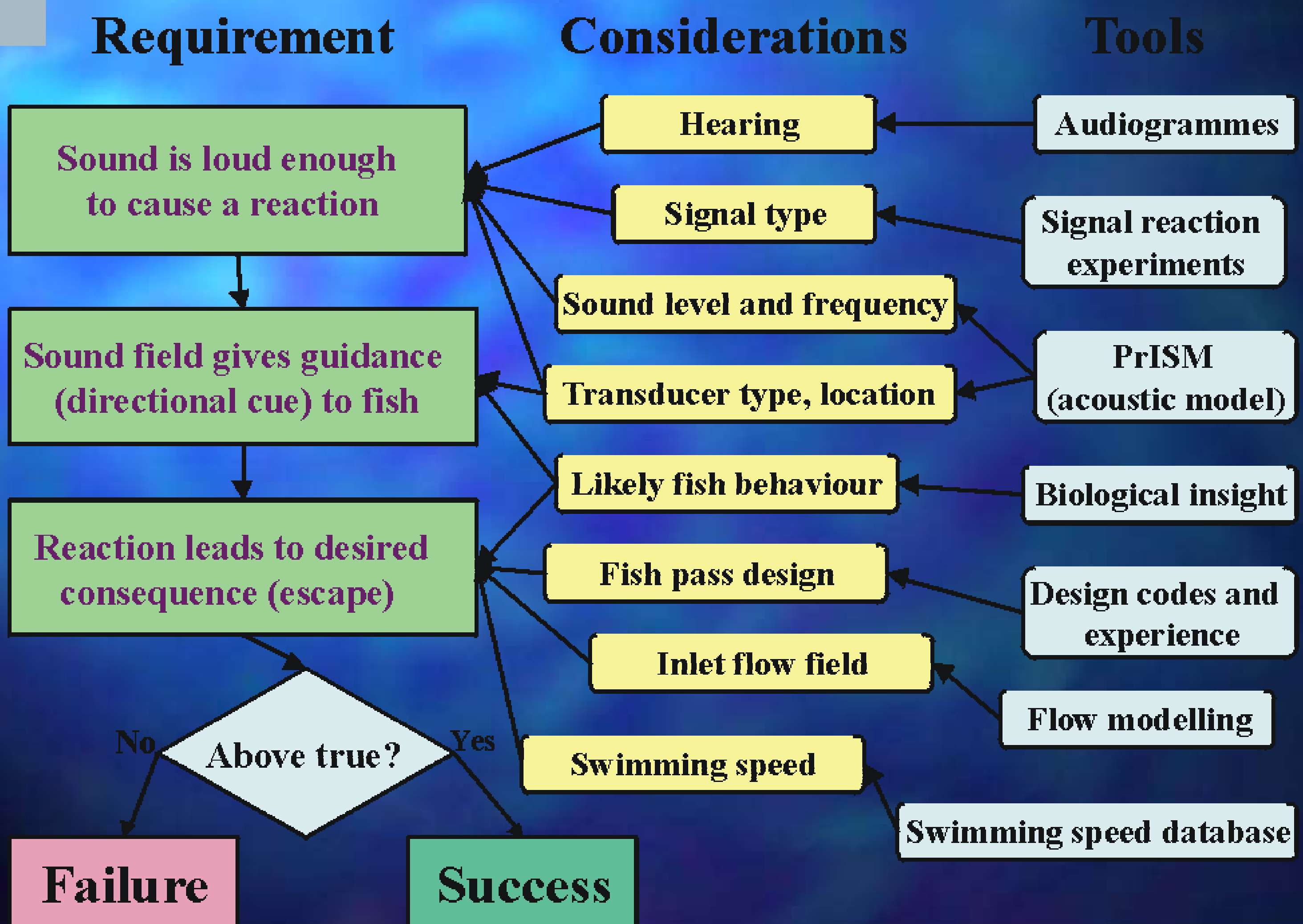
- The Acoustic Fish Deterrent (AFD) system at Doel nuclear power station was successful, but efficiency varied from species to species
- Why?
- How is it possible to use the information from Doel to design other systems?

# Engineering questions raised by Doel

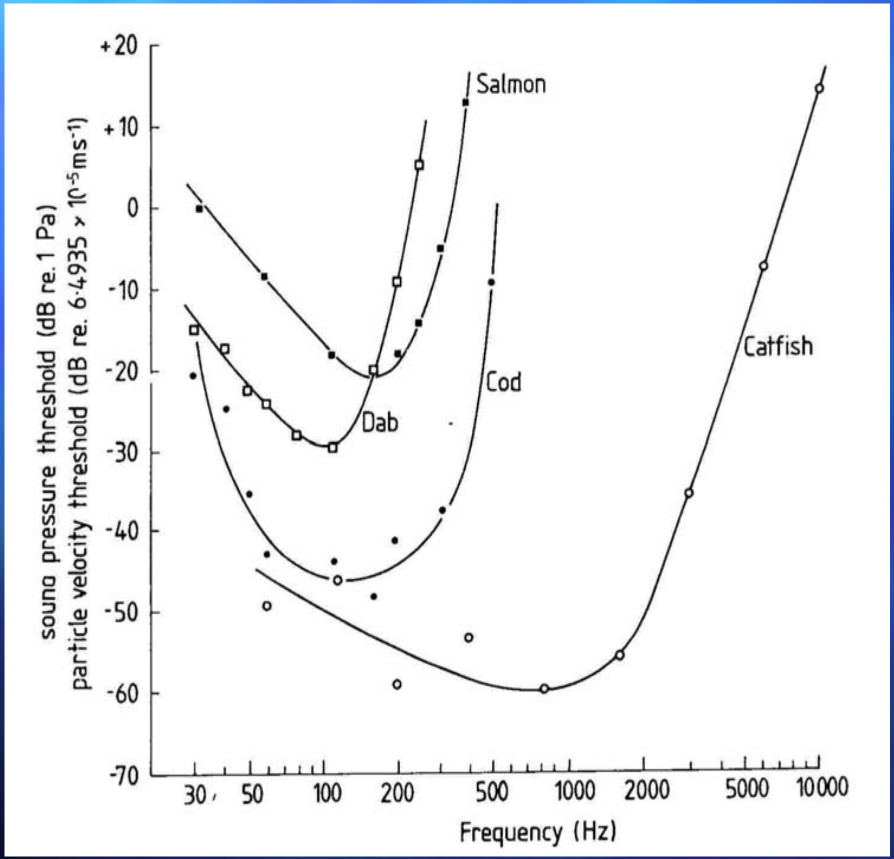
**For design to be engineering rather than an art:**

- can the differing efficiency for different species be accounted for?
- How is the percentage efficiency related to the level and frequency of the sound?
- Is it possible to design systems for a given efficiency?

# Requirements for effective system



# Fish Audiograms

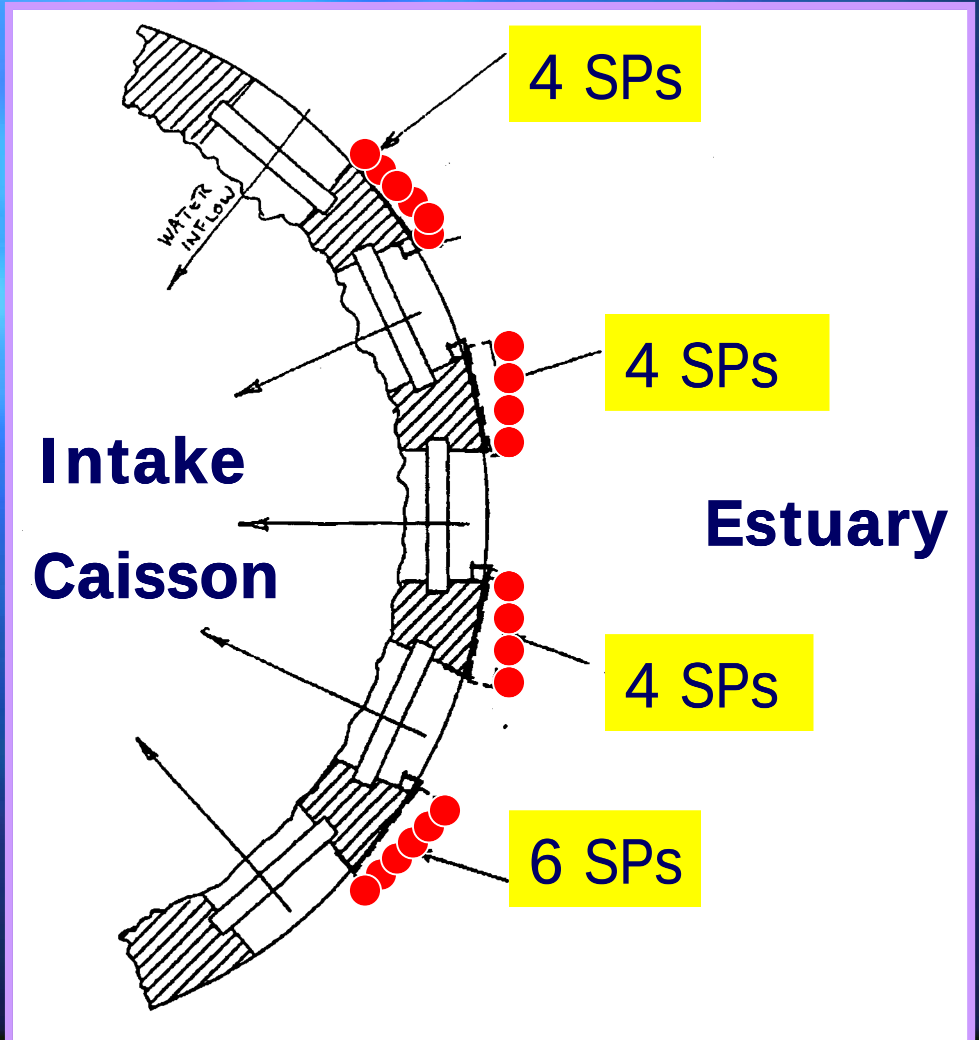



- Most fish are sensitive to sounds less than 3000Hz
- The $dB_{ht}$(Species) is the peak pressure after passing through the species-specific audiogram ‘filter’’

# The $dB_{ht}$(Species)

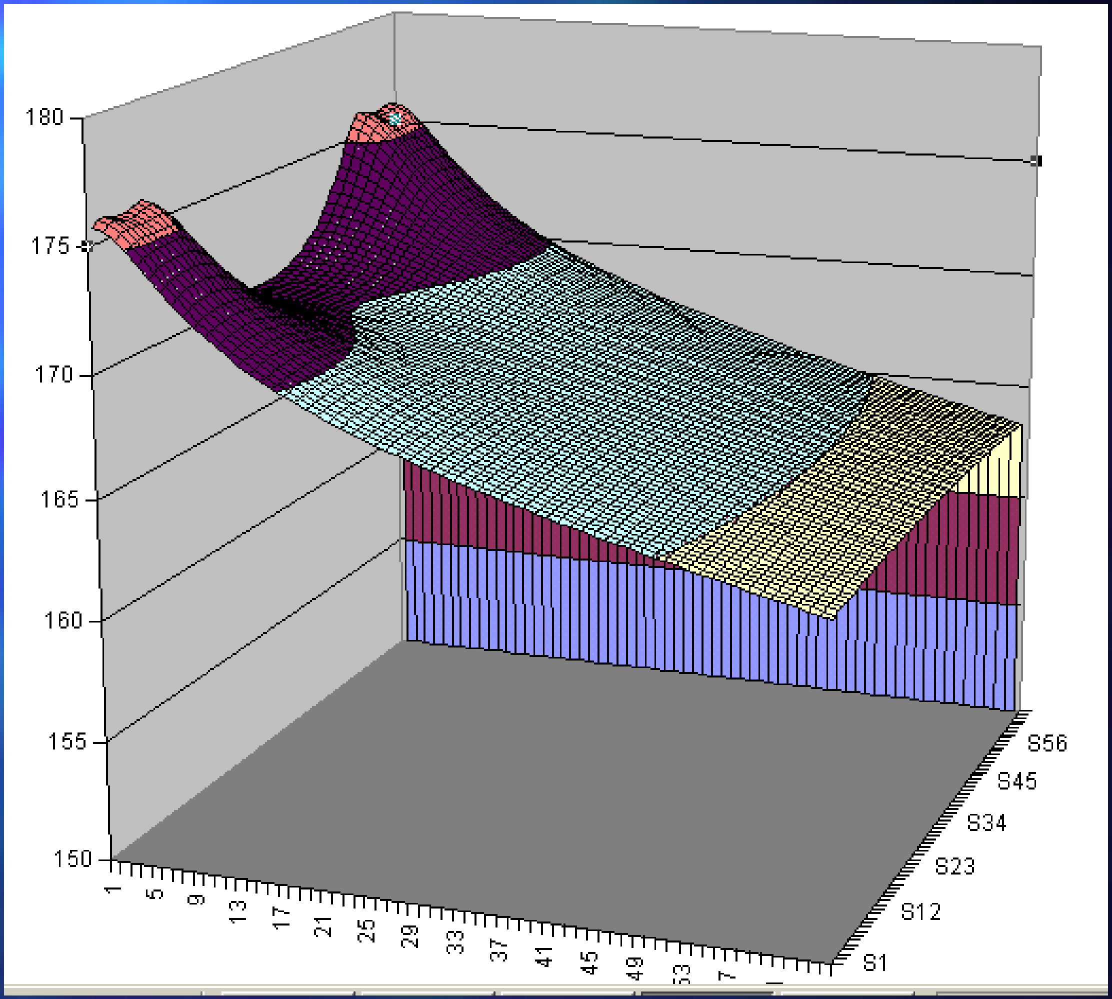
- $dB_{ht}$(Species): frequency dependent filter is used to weight the sound.
- Suffix 'ht' relates to the fact that the sound is weighted by the hearing threshold of the species.
- For each species this is derived from the audiogram

# Doel Sound Projector Layout- *Arrangement 2*



# Pressure; Doel inlet

- Example of output of PrISM model
- Pressure; dB re 1 μPa
- Can also calculate $dB_{ht}$ levels



# Efficiency of Doel system *vs* $dB_{ht}$(Species) level

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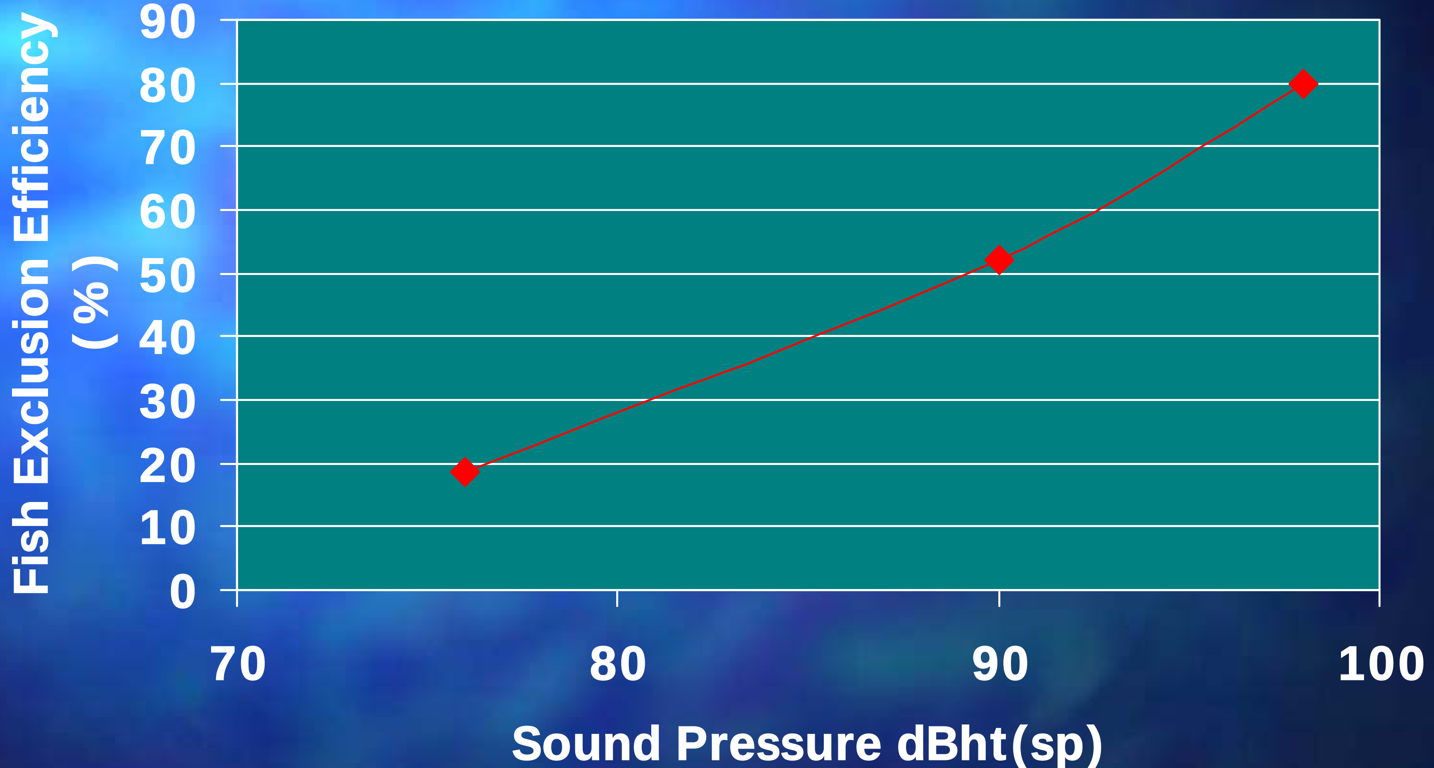
The $dB_{ht}$(Species) levels shown here were calculated from sound pressure levels measured at Doel and processed using the species audiograms

| **Modelled $dB_{ht}$(*Species*) level for Doel system** | **Doel system efficiency** | **Hartlepool system efficiency** |
|---|---|---|
| 76 $dB_{ht}$(*Limanda limanda*) | 21% (flatfish results) | 16% (flatfish results) |
| 90 $dB_{ht}$(*Gadus morhua*) | 50% (roundfish results) | 54% (whiting results) |
| 98 $dB_{ht}$(*Clupea harengus)* | 80% | 80% |

**Table 1: The estimated average level at the inlet *vs* the system efficiency**

# Required Sound Level




Tentative results for deflection efficiency *vs* sound level

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# Conclusions

- The differing efficiency of AFDs for different species can be accounted for in terms of the level of sound *perceived* by the species
- Systems having a sound level of 90 $dB_{ht}$ and above for a given species are likely to generate effective deflection for that species
- Efficient fish deflection should be achievable for most species, given an adequate sound level